Recent Results on non$-D\bar{D}$ decays of $\psi(3770)$ from BES

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BES Collaboration measured the R values at 3.650, 3.6648 and 3.773 GeV, the R values at 68 energy points in the energy region between 3.650 and 3.872 GeV, the resonance parameters of $\psi(3686)$ and $\psi(3770)$, the branching fractions for $\psi(3770) \rightarrow D^0\bar{D}^0, D^+D^-, D\bar{D}$ and non-$D\bar{D}$, and the observed cross sections for some exclusive light hadron final states at 3.773 and 3.650 GeV. These measurements are made by analyzing the data sets collected with the BESII detector at the BEPC collider.

1 Introduction

There is a long standing puzzle that the observed cross section $\sigma_{D\bar{D}}^{\mathrm{obs}}$ for $D\bar{D}$ production at the $\psi(3770)$ peak is less than the observed cross section $\sigma_{\psi(3770)}^{\mathrm{obs}}$ for $\psi(3770)$ production [1]. Precise or direct measurements of the R values at 3.650, 3.6648 and 3.773 GeV [2], the R values in the energy region between 3.650 and 3.872 GeV [3], the resonance parameters of $\psi(3686)$ and $\psi(3770)$ [4,5], the branching fractions for the $\psi(3770)$ decays [2,4] and the observed cross sections for more exclusive light hadron final states produced in e^+e^- annihilation at 3.773 and 3.650 GeV [6] are important to understand the discrepancy. In addition, precise measurements of the R values are also important to test the validity of the pQCD calculation in this energy region and to calculate the effects of vacuum polarization on the parameters of the standard model [2,3]. In this paper, we report the results of these measurements.

For convenience, we call the data taken at the c.m. (center-of-mass) energies of 3.650, 3.6648 and 3.773 GeV, the data taken at 49 energy points in the energy region between 3.660 and 3.872 GeV in March 2003, the data taken at 68 energy points in the energy region between 3.650 and 3.872 GeV in December 2003 to be the data A, the data B and the data C, respectively.

2 Measurements of R values

With the data A, we measured the lowest order cross sections $\sigma_{\mathrm{had}}^{\mathrm{obs}}$ and the R values ($R = \sigma_{e^+e^-\rightarrow\mathrm{hadrons}}^0 / \sigma_{e^+e^-\rightarrow\mu^+\mu^-}^0$) for inclusive hadron production at 3.650, 3.6648 and 3.773 GeV. These results [2] are summarized in Table 1, where the first error is the combined statistical and point-to-point systematic error, and the second is the common systematic.

Table 1: The measured $\sigma_{\mathrm{had}}^{\mathrm{obs}}$ and R values for inclusive hadron production at 3.650, 3.6648 and 3.773 GeV.

E_{cm} (GeV)	3.6500	3.6648	3.7730
$\sigma_{\mathrm{had}}^{\mathrm{obs}}$[nb]	$18.98 \pm 0.20 \pm 0.76$	$18.30 \pm 0.27 \pm 0.73$	$27.68 \pm 0.27 \pm 1.38$
R_{had}	$2.26 \pm 0.02 \pm 0.09$	$2.31 \pm 0.03 \pm 0.09$	$3.75 \pm 0.04 \pm 0.19$
R_{uds}	$2.24 \pm 0.02 \pm 0.09$	$2.19 \pm 0.03 \pm 0.09$	-
$R_{\mathrm{uds}+\psi(3770)}$	-	-	$3.75 \pm 0.04 \pm 0.19$

With the data C, we also measured the continuum R_{uds} below the $D\bar{D}$ production, the $R_{\mathrm{uds(c)}+\psi(3770)}(s)$ and the $R_{\mathrm{had}}(s)$ values in e^+e^- annihilation at all of the 68 energy points [3]. They are compared with the other measurements in Fig. 1.

3 Measurements of resonance parameters of $\psi(3686)$ and $\psi(3770)$

A better way to measure the branching fractions for $\psi(3770) \rightarrow D\bar{D}$ is to simultaneously analyze the energy-dependent cross sections for the inclusive hadron, $D^0\bar{D}^0$ and D^+D^- production in the energy range covering both the $\psi(3686)$ and $\psi(3770)$. We first accurately measured the
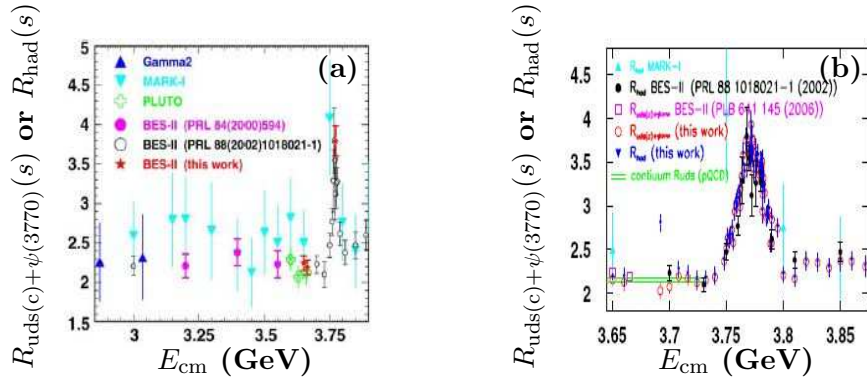
Figure 1: The measured R values (a) at 3.650, 3.6648 and 3.773 GeV and (b) at 68 energy points in the energy region between 3.650 and 3.872 GeV, compared with the other measurements.

resonance parameters of the two resonances[4] by fitting the observed cross sections at 49 energy points from the data B. In addition, we reported precision measurements of the mass, the total width and the partial leptonic width of the $\psi(3770)$ by further analyzing the measured R values at 68 energy points[5] from the data C. The fits to the energy-dependent observed cross sections $\sigma_{\mathrm{had}}^{\mathrm{obs}}$ and the R values for inclusive hadron production are shown in Fig. 2. The fitted results are summarized in Table 2.
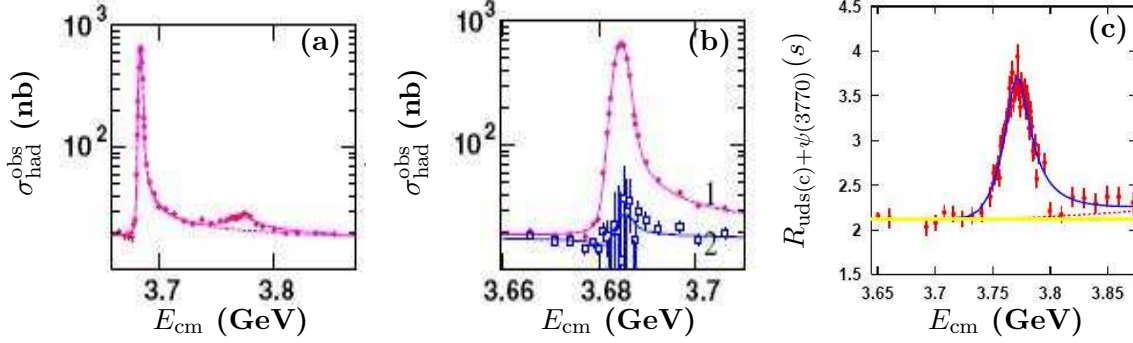

Figure 2: The fits to the observed cross sections $\sigma_{\mathrm{had}}^{\mathrm{obs}}$ and the $R_{\mathrm{uds(c)}+\psi(3770)}$ values versus E_{cm}, where the lines show the fits, (a) and (b) are from the data B and (c) is from the data C.

Table 2: Summary of the measured resonance parameters of the $\psi(3770)$ and $\psi(3686)$, where M is the mass, Γ^{tot} is the total width, Γ^{ee} is the partial leptonic width and ΔM is the mass difference of the $\psi(3770)$ and $\psi(3686)$.

Res.	Ref.	M(MeV)	Γ^{tot}(MeV)	Γ^{ee}(eV)	ΔM(MeV)
$\psi(3770)^{\mathrm{B}}$	4	$3772.2 \pm 0.7 \pm 0.3$	$26.9 \pm 2.4 \pm 0.3$	$251 \pm 26 \pm 11$	
$\psi(3686)^{\mathrm{B}}$	4	$3685.5 \pm 0.0 \pm 0.3$	$0.331 \pm 0.058 \pm 0.002$	$2330 \pm 36 \pm 110$	86.7 ± 0.7
$\psi(3770)^{\mathrm{C}}$	5	$3772.4 \pm 0.4 \pm 0.3$	$28.6 \pm 1.2 \pm 0.2$	$279 \pm 11 \pm 13$	

4 Determinations of R_{uds} and $\sigma_{\psi(3770)}$

Averaging the measured R_{uds} values at 3.650 and 3.6648 GeV from the data A listed in Table 1 by the combined statistical and point-to-point systematic error, we obtain $\bar{R}_{\mathrm{uds}} = 2.218 \pm 0.019 \pm 0.089$, where the first error is the combined statistical and point-to-point systematic error, and the second is the common systematic.

Fitting to the energy-dependent $\sigma_{\mathrm{had}}^{\mathrm{obs}}$ from the data B yields $R_{\mathrm{uds}} = 2.262 \pm 0.054 \pm 0.109$ in the energy region between 3.660 and 3.872 GeV. Fitting to the measured R values at 68 energy

points from the data C yields $R_{\text{uds}} = 2.121 \pm 0.023 \pm 0.084$ in the energy region between 3.650 and 3.872 GeV. Here, the errors are statistical and systematic, respectively.

Ignoring the contribution from the continuum $D\bar{D}$ production at the $\psi(3770)$ peak, we obtained from the data A to be $R_{\psi(3770)} = 1.528 \pm 0.042 \pm 0.131$ due to $\psi(3770)$ decay into hadrons with the measured $R_{\text{uds}+\psi(3770)}$ value at 3.773 GeV as listed in Table 1 and $\bar{R}_{\text{uds}}$ measured below $D\bar{D}$ threshold. This lead to the lowest order cross section $\sigma^0_{\psi(3770)}$ and the observed cross section $\sigma^{\text{obs}}_{\psi(3770)}$ for $\psi(3770)$ production at 3.773 GeV. The resonance parameters of the $\psi(3770)$ obtained by fitting to the energy-dependent $\sigma^{\text{obs}}_{\text{had}}$ or fitting to the $R_{\text{uds(c)}+\psi(3770)}$ values from analyzing the cross section scan data samples can further give $\sigma^0_{\psi(3770)}$ and $\sigma^{\text{obs}}_{\psi(3770)}$ at $\psi(3770)$ peak. They are summarized in Table 3.

Table 3: Summary of the measured $\sigma^0_{\psi(3770)}$ and $\sigma^{\text{obs}}_{\psi(3770)}$ at 3.773 GeV or its peak.

Data Sample	Ref.	$\sigma^0_{\psi(3770)}$[nb]	$\sigma^{\text{obs}}_{\psi(3770)}$[nb]
A	2	$9.323 \pm 0.103 \pm 0.801$	$7.179 \pm 0.195 \pm 0.630$
B	4	$9.63 \pm 0.66 \pm 0.35$	$6.94 \pm 0.48 \pm 0.28$
C	5	$10.06 \pm 0.37 \pm 0.43$	$7.25 \pm 0.27 \pm 0.34$

5 Measurements of branching fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^-, $D\bar{D}$ and non$-D\bar{D}$

Assuming that there are no other new structures and effects except the $\psi(3770)$ resonance and the continuum hadron production in the energy region from 3.70 to 3.86 GeV, we can determine [2] the branching fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^-, $D\bar{D}$ and non$-D\bar{D}$ with the measured $\sigma^{\text{obs}}_{\psi(3770)}$ and the observed cross sections [7,8] $\sigma^{\text{obs}}_{D^0\bar{D}^0}$, $\sigma^{\text{obs}}_{D^+D^-}$ and $\sigma^{\text{obs}}_{D\bar{D}}$ for $D^0\bar{D}^0$, D^+D^- and $D\bar{D}$ production measured by analyzing the same data sample A. Fitting to the energy-dependent $\sigma^{\text{obs}}_{\text{had}}$, $\sigma^{\text{obs}}_{D^0\bar{D}^0}$, $\sigma^{\text{obs}}_{D^+D^-}$ and $\sigma^{\text{obs}}_{D\bar{D}}$ in the energy range covering both the $\psi(3686)$ and $\psi(3770)$ from the data B, we can also measured the branching fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^-, $D\bar{D}$ and non$-D\bar{D}$. The measured branching fractions are summarized in Table 4.
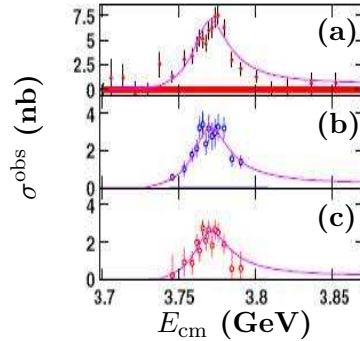

Figure 3: The observed cross sections versus E_{cm} with fits, where (a) shows inclusive hadron cross section, (b) and (c) show the $D^0\bar{D}^0$ and D^+D^- cross sections, respectively.

Table 4: The measured branching fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^-, $D\bar{D}$ and non-$D\bar{D}$.

$\psi(3770) \to$	Ref.	$D^0\bar{D}^0$	D^+D^-	$D\bar{D}$	non-$D\bar{D}$
$\mathcal{B}^{\text{A}}[\%]$	2	$49.9 \pm 1.3 \pm 3.8$	$35.7 \pm 1.1 \pm 3.4$	$85.5 \pm 1.7 \pm 5.8$	$14.5 \pm 1.7 \pm 5.8$
$\mathcal{B}^{\text{B}}[\%]$	4	$46.7 \pm 4.7 \pm 2.3$	$36.9 \pm 3.7 \pm 2.8$	$83.6 \pm 7.3 \pm 4.2$	$16.4 \pm 7.3 \pm 4.2$

6 Measurements of the observed cross sections for some exclusive light hadron final states produced in e^+e^- annihilation at 3.773 and 3.650 GeV

We measured the observed cross sections for the exclusive light hadron final states of $\phi\pi^0$, $\phi\eta$, $\phi\pi^+\pi^-$, ϕK^+K^-, $\phi p\bar{p}$, $2(\pi^+\pi^-)\eta$, $2(\pi^+\pi^-)\pi^0$, $K^+K^-\pi^+\pi^-\pi^0$, $2(K^+K^-)\pi^0$, $p\bar{p}\pi^0$, $p\bar{p}\pi^+\pi^-\pi^0$ and $3(\pi^+\pi^-)\pi^0$ produced in e^+e^- annihilation at $\sqrt{s} = 3.773$ and 3.650 GeV. The preliminary results [6] are shown in Table 5, where the upper limits are set at 90% C.L.. We ignore the interference effects between the continuum and resonance amplitudes, since we do not know the details about the two amplitudes. Therefore we can not draw a conclusion that the $\psi(3770)$ does not decay into these final states even if we do not observe significant difference between the observed cross sections for most light hadron final states at the two energy points.

Table 5: Comparisons of the observed cross sections for $e^+e^- \to$ exclusive light hadrons at 3.773 and 3.650 GeV.

Final State	$\sigma^{(up)}_{e^+e^-\to f}$(@3.773 GeV)[pb]	$\sigma^{(up)}_{e^+e^-\to f}$(@3.650 GeV)[pb]
$\phi\pi^0$	< 3.5	< 8.9
$\phi\eta$	< 12.6	< 18.0
$\phi\pi^+\pi^-$	< 11.1	< 22.9
ϕK^+K^-	$15.8 \pm 5.1 \pm 1.8$	$17.4 \pm 9.2 \pm 2.0$
$\phi p\bar{p}$	< 5.8	< 9.1
$2(\pi^+\pi^-)\eta$	$153.7 \pm 40.1 \pm 18.4$	$86.6 \pm 40.3 \pm 10.4$
$2(\pi^+\pi^-)\pi^0$	$80.9 \pm 13.9 \pm 10.0$	$124.3 \pm 21.7 \pm 14.9$
$K^+K^-\pi^+\pi^-\pi^0$	$171.6 \pm 26.0 \pm 20.9$	$222.8 \pm 37.7 \pm 27.2$
$2(K^+K^-)\pi^0$	$18.1 \pm 7.7 \pm 2.1$	< 23.0
$p\bar{p}\pi^0$	$10.1 \pm 2.2 \pm 1.0$	$9.2 \pm 3.4 \pm 1.0$
$p\bar{p}\pi^+\pi^-\pi^0$	$53.1 \pm 9.2 \pm 6.8$	$29.0 \pm 11.1 \pm 3.7$
$3(\pi^+\pi^-)\pi^0$	$105.8 \pm 34.4 \pm 16.9$	$126.6 \pm 47.1 \pm 19.2$

7 Summary

Using the data sets collected with the BESII detector at the BEPC collider, BES Collaboration measured the R values at 3.650, 3.6648 and 3.773 GeV, the R values in the energy region between 3.650 and 3.872 GeV, the resonance parameters of $\psi(3686)$ and $\psi(3770)$, the branching fractions for $\psi(3770) \to D^0\bar{D}^0, D^+D^-, D\bar{D}$ and non-$D\bar{D}$, and the observed cross sections for some exclusive light hadron final states at 3.773 and 3.650 GeV.

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